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THE PLANNING OF INTEGRATED STEM EDUCATION BASED ON STANDARDS AND CONTEXTUAL ISSUES OF SUSTAINABLE DEVELOPMENT GOALS (SDG)

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ABSTRACT

Two important features in Science Technology Engineering Mathematics (STEM) education are integration and solving real world problems. Despite the efforts to promote STEM education awareness and interest among students and teachers, documented studies on how to explicitly integrate the existing STEM subjects curriculum standards in solving real world problems are limited. This paper describes the planning of after-school STEM education program focusing on relevant global issues related to Sustainable Development Goals (SDG) that integrates the existing curriculum standards of three STEM subject in the lower secondary level. The data collection is mainly through document analysis of the three individual STEM subjects' standard documents and the planned curriculum map for the school, along with the document on 'Education for Sustainable Development Goals Learning Objectives'. Four possible design challenges were formulated based on the themes in SDG incorporating selected standards from the three STEM subjects as well as addition of a few new related concepts and skills. The description offers a way to assist educators in planning similar STEM education lesson or programmes or activities through integration of the existing individual STEM disciplines curriculum standards for different level and context relevant to the students.

Keywords: Contextual problem solving, integration, standard-based, STEM education, Sustainable Development Goals (SDG).

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1.0 INTRODUCTION

Currently there is active promotion of science, technology, engineering and mathematics (STEM) education through many initiatives and activities by the Malaysia Ministry of Education, mainly to promote STEM education awareness and interests among students, teachers and parents. In the formal school curriculum, STEM education is described as a STEM related individual subject, a learning package offering learning pathway for STEM elective subjects and as an integrated STEM approach (Ministry of Education, 2016). The description of STEM education as discrete STEM subjects and learning package have a long standing in the previous and current curriculum. The definition of STEM education as an integrated approach that blends the STEM content, skills and values in solving contextual problem seems to agree with that in many of the literature (eg. Jolly, 2017; Kelley & Knowles, 2016; Kennedy & Odell, 2014; Kim, Chu, & Lim, 2015; Truesdell, 2014; Vasquez, 2014; Xie, Fang, & Shauman, 2015). Therefore, educators here may subscribe to one of the given descriptions in implementing STEM education. Nevertheless, many teachers may not be familiar with integrated STEM as an approach in teaching and learning. Therefore, guidelines and some resources are provided in order to assist educators to implement integrated STEM as an approach in classroom teaching and learning.

In the Implementation Guidelines for STEM Education in Teaching and Learning by the Ministry of Education (Ministry of Education, 2016), there are general guidelines and a few teaching plan examples to assist teachers to carry out integrated STEM education during class or co-curricular activities. Further description and application of STEM education as an approach is found in the recent STEM resource modules for Physics, Chemistry, Biology, Additional Mathematics, Computer Science and Design and Invention (*Rekacipta*) respectively (Curriculum Development Division, 2017e, 2017d, 2017f, 2017b, 2017a, 2017c). These six STEM resource modules are based on solving contextual problem related to the content for each discipline. Detail description of the approach used, content and activity teaching plan, pretests and post-tests, students' activity sheets, assessment rubrics and references are included in each book. The comprehensive resource aimed to assist teacher before, during and after the teaching and learning session. As for the students, the modules emphasize the application of design process and scientific inquiry as the main approaches in solving contextual issues. However, the degree of STEM content and skills integration in each subject varies depending on the issues or problems posed for each topic. These resource modules are among some of the initial resources available for the teachers at the time of writing. They are targeted for the upper secondary school students who are in the pure science and technical classes which may not meet the needs of other students especially those in the lower secondary level. More teaching and learning materials on integrated STEM education have to be developed for all levels of students. The design of the series also aimed to serve as a model for teachers to develop their own STEM education material for other topics in the future. Hence, teachers can plan, develop and implement their own integrated STEM lessons or programs that suit the context of their own students.

This paper describes the planning of an after-school or co-curricular STEM education program to complement the formal classroom teaching and learning. The description offers a way to assist educators in planning similar STEM education lesson or programs or activities through integration of the existing individual STEM disciplines curriculum standards. It focuses on the multidisciplinary aspect of STEM integration in which organizes and connects related concepts and skills of the STEM disciplines through engineering design practice (EDP) in order to solve a contextual problem. The contextual problems are relevant global issues described in the Sustainable Development Goals (SDG) by UNESCO (2017) that differs from many of the simulated or written problems that are often used in the traditional classroom teaching and learning. Contextual issues that are based on one of the SDGs not only make learning relevant and meaningful, it empowers the students to make informed decisions and responsible actions in relation to their local social, cultural, economic and environmental context. It elicits the students' beliefs in their potential in making the world more sustainable by the application of STEM knowledge and skills.

2.0 LITERATURE REVIEW

2.1 STEM Education

Integration is one of the main features that define STEM education. It makes the STEM subjects more relevant as many of the real life situations, problems and decisions involve the blending of multiple STEM knowledge and skills (National Research Council & National Academy Of Engineering, 2014). Most of the challenging global issues such as energy crisis, poverty, climate change and many more require collaborations between STEM disciplines Integration provides more value compared to the subjects learned separately (Bybee, 2013; Vasquez, 2014). Nevertheless, the nature of integration in STEM education is perhaps one of the aspects that lack of consensus worldwide. There is no definite way in defining how the STEM disciplines are integrated. This remains a challenge due to the various ways of STEM integrations (Bybee, 2013; National Research Council & National Academy of Engineering, 2014). It can be a multidisciplinary approach involves learning of concepts and skills separately in each discipline but in reference to a common theme (Vasquez, 2014); or the interdisciplinary approach that organizes some closely related concepts or skills of the STEM disciplines to solve a contextual problem (Bybee, 2013; Vasquez, 2014); or the transdisciplinary approach in which an ill-structured real world problem serves as a basis for application of the entire STEM disciplines in order to understand and solve the issue (Bybee, 2013; Kelley & Knowles, 2016; Vasquez, 2014). As it moves from multidisciplinary to transdisciplinary, the boundary between the subjects becomes less obvious.

In the multidisciplinary perspective, the content and skills of individual STEM subjects are taught separately but connected through a theme. The integration between the subjects are not made explicitly by the teachers, but students are expected to make the connections (Drake, 2012). However, an integrated final project can be implemented that blend the content of the different subject areas. Similarly, in the interdisciplinary perspective, the content and skills are centered around a theme or issue, but the connections across the subjects are more obvious. The skills and concepts are not taught separately but rather they are emphasized across the subjects. The transdisciplinary approach does not begin with common concepts or skills between the STEM disciplines but it starts with a problem in the real life situation. In this approach, students ask questions, apply the related STEM content and skills to design a product or solution that address the issue. This is usually implemented through project based learning, an effective student-centred instructional strategy that allows deep learning and application of concepts in new settings (Larmer, Mergendoller, & Boss, 2015). Despite the differences between the four integration approaches, all of the approach can be designed using the available individual STEM subjects curriculum standards set in a student-relevant real world context (Drake, 2012).

Bryan, Moore, Johnson, and Roehrig (2016) argued that meaningful connection between STEM disciplines can be created through learning goals derived from selected primary disciplines; application of engineering design practices (EDP) as the integrator; application of science and mathematics in design or solution justification by students; the inclusion of 21st century skills in learning; the focus of contextual problem solving. In fact, the application of EDP as the main integrator of STEM education (Bryan et al., 2016; Guzey & Moore, 2015; Jolly, 2017; Kelley & Knowles, 2016; Moore et al., 2014; National Research Council & National Academy of Engineering, 2014; Truesdell, 2014), provides a systematic approach to solve problems, allowing the application of scientific knowledge and inquiry process and providing opportunity for students to build science and mathematical knowledge through design analysis and scientific investigation (Kelley & Knowles, 2016; National Research Council & National Academy of Engineering, 2014). Therefore, by applying EDP, there is a blending of scientific, mathematical and technological concepts and skills in exploring the possible solutions, selecting and planning solutions, developing and testing the solution. It is also an approach that incorporates the 21st century skills of critical thinking and creativity. In terms of collaboration and communication, EDP provides a platform for team work and active discussion in the process of designing, presenting and justifying the solution. Therefore, design process promotes content connection. This study focuses on the interdisciplinary aspect of STEM integration in which organizes and connects related concepts and skills of the STEM disciplines through EDP in order to solve a contextual problem.

2.2 Contextual Problem and Sustainable Development Goals (SDG)

Another feature that defines STEM education is the focus on contextual problem solving. This differs from many of the simulated problems or written problems that are often used in the traditional classroom teaching and learning. Contextual problem refers to real world issues that are relevant in our daily life situation. Learning in context improves students' interest and making learning more meaningful (Pilot & Bulte, 2006). By applying integrated STEM in relevant real world situations, students are more competent and embedded in the surrounding community (Sevian, Dori, & Parchmann, 2018). Educators may select any contextual global issues as a focus for STEM education programs. However, consideration need to be given to its relevance and impact to the students, community and surroundings. In 2017, the United Nation (UN) general assembly adopted the 2030 agenda that listed 17 Sustainable Development Goals (SDGs) (Appendix 1) that cover global challenges that need to be addressed for a sustainable, peaceful, prosperous and equitable life of humanity in this world

(UNESCO, 2017). It is a globally agreed agenda on the major challenges that the world is facing in the 21st century. Various global issues such as climate change, hunger and poverty require a shift and transformation of lifestyle, thinking and action. The next generation need to acquire new mind-set, skills, values and attitudes to achieve this change that may lead to a more sustainable world. One of the important strategies to achieve the SDGs is through education and UNESCO has been promoting education for sustainable development since 1992. The comprehensive descriptions of the cognitive, socio-emotional and behavioural learning outcomes as well as recommended strategies are listed in the ESD in achieving the SDGs. It presents a systematic and exhaustive manner on various possibilities on how to approach the SDGs.

UNESCO (2017) lists three important features of ESD which are student-centered, action oriented and transformative learning. Integrated STEM education can be used as one of the approaches of education for sustainable development in achieving the SDGs listed in the 2030 Agenda in the UN general assembly (Pitt, 2009). STEM education is a student-centered approach requiring students to self-direct and collaborate in groups to produce a solution, product, prototype or design driven through project that is ill-defined but with well-defined outcome (Sahin, 2013). STEM education is action oriented as it involved solving real issues that are situated in the learners' own context. Finally, STEM education is able to empower and challenge learners to perceive the world differently in which they have the potential in making the world sustainable by the application of STEM knowledge and skills. Therefore, STEM education can be a vehicle in achieving the SDGs as learners can integrate various STEM knowledge, skills and attitudes that empower them to solve global issues in their local context.

Contextual issues in integrated STEM education that are based on one of the SDGs not only make learning relevant and meaningful, it empowers the students to make informed decisions and responsible actions in relation to their local social, cultural, economic and environmental context. It elicits the students' beliefs in their potential in making the world more sustainable by the application of STEM knowledge and skills.

3.0 METHODOLOGY

This study employed a qualitative descriptive case study that focuses on a bounded phenomenon to yield rich information and provide insights into an issue (Merriam, 1998; Stake, 1995). The case under consideration is the planning of Grade 7 (Form 1) after-school integrated STEM program in one of the secondary schools. The purposive sampling specifically the typical case sampling strategy (Patton, 2002) was used, to reveal and represent what was common about the case in the district. The selection of school was based on the performance ranking based on national standardized examination results in the district. A school that ranked at 10th position out of 20 schools was selected to reveal the 'average-like' case here.

The data collection procedure was mainly through document analysis of the Grade 7 STEM related subjects curriculum standard documents known as DSKP (*Dokumen Standard Kurikulum dan Pentaksiran*), curriculum map of the yearly teaching plans and Education for Sustainable Development Goals' Learning Objectives (UNESCO, 2017). For this study, DSKP for the subjects of Science, Mathematics and Design of Technology (*Rekabentuk Teknology, RBT*) were analyzed. Document analysis is an analytic method in qualitative study that examines and interprets data to draw meaning, gain understanding and develop empirical knowledge (Stake, 1995). It is efficient and cost effective as many documents are available in public domain either in printed or electronic forms (Bowen, 2009). However, some documents may have to be obtained with the permission from the authors or from the school administration. In this study, the DSKPs and Education for SDG learning objectives document were obtained from the internet while the yearly teaching plans of the STEM subjects were obtained from the school with permission. Yearly teaching plan of a subject is the school's subject panel projected teaching plan throughout the year. The curriculum map is a synthesis of the combined yearly teaching plans and DSKP of the STEM related subjects to identify the scope, sequence, overlaps in concepts and skills across the disciplines, in order to find potential areas for integration (see Appendix 2).

In analyzing the documents, this study involved the iterative process of scanning, reading and interpretation which combined the elements of content analysis and thematic analysis (Bowen, 2009). Content analysis was used to identify keywords related to STEM disciplines and their frequency in the SDG description. Content analysis examines text and yield numerical features of a given text. It also involved systematically and objectively identifying characteristics and establishing categories in the text (Joffe & Yardley, 2004). Certain level of interpretation was applied when matching the keywords in the SDG description with the themes in the curriculum standards of the three Grade 7 STEM subjects.

From the DSKPs, the main themes, learning areas and /or topics were listed out for each subject in three tables (Appendix 1) The yearly teaching plan for the three subjects were displayed in a curriculum map (Appendix 2). The UNESCO's SDGs and their respective learning objectives descriptions were analyzed for words and terms related to STEM disciplines. The terms were identified, listed and tabulated (Table 1). Next, the learning standards of the Grade 7 STEM disciplines were clustered and matched into the relevant keywords. For example, the keyword 'sustainable agriculture' in the SDG description can relate to the concept of photosynthesis and plant reproduction in the subject of science, and fertigation system in the subject of RBT. Upon fitting the standards to the relevant SDGs, design challenges that relate to the SDGs and the local context of the students were formulated. Figure 1 summarizes the process of document analysis in combining the relevant STEM content with the design challenge.

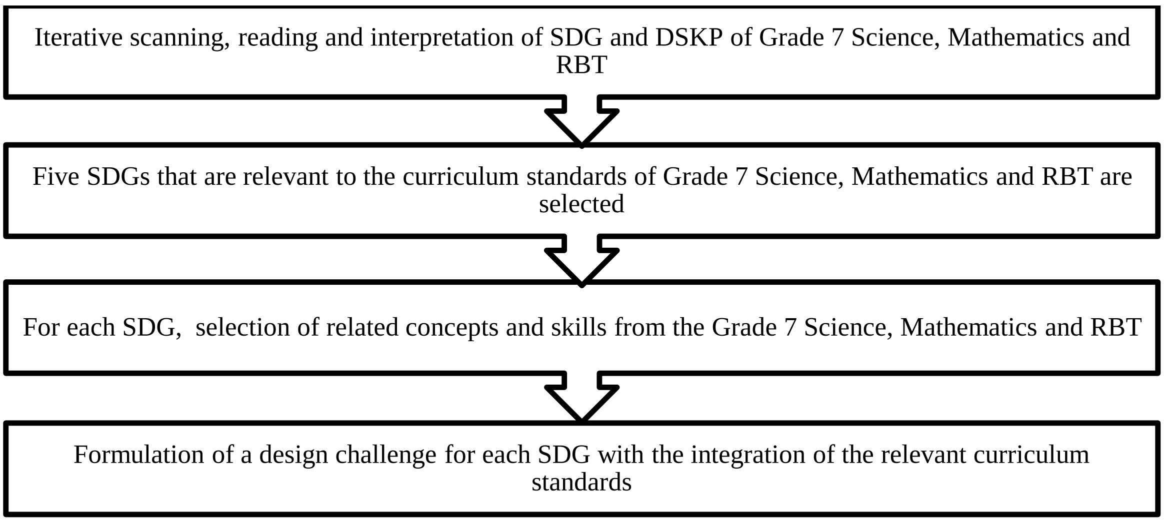

Figure 1: Summary of the document analysis process

4.0 RESULTS AND DISCUSSION

Terms and words related to STEM disciplines were found in 13 out of the 17 SDGs (Appendix 3). However, only 11 SDGs have close relations with STEM disciplines. SDG 5 and SDG 8 only contain one word that can relate to STEM disciplines and their focus is more on the social and economic aspects of the global issues.

Four design challenges were formulated with the combination of relevant concepts and skills from the curriculum standards of the three STEM subjects as presented in Appendix 4 3, 4 and 5. For example, Table 1 is the design challenge related to the theme Zero Hunger in the SDG, the key word 'sustainable agriculture' which appears nine times in the SDG description, was used to identify related concepts and skills required. Science content and skills regarding cell respiration and photosynthesis, plant reproduction, scientific inquiry, quantities and measurement are incorporated in this design challenge. In RBT, fertigation system, concepts and skills related to design process such as project management, sketching and brief project are integrated. Similarly, for Mathematics, it will most probably involve the concepts and skills of ratio, rates and proportion, area and perimeter and data handling which may be useful in design process.

Similarly, in Sustainable Cities and Communities (Table 2) and SDG about Responsible Consumption and Production (Table 3), the key words 'integration of green spaces' and 'sustainable production and consumption' are also related to sustainable agriculture which are actually mentioned in the learning objectives and suggested approaches in the respective SDG. This ended up with the three SDGs having the same combination of standards for the three subjects. However, the goals of both the SDGs are different. In Zero Hunger, it is aimed to solve and reduce hunger and achieve food security; in Sustainable Cities and Communities, its purpose is to make cities, towns, residential sustainable; and in Responsible Consumption and Production it is to promote sustainable consumption and production. The choice will depend on the relevance of the purpose of the SDG to the lives of the students. In Responsible Consumption and Production, the RBT standard on fashion design can also be selected together with the standard regarding matter in science to promote sustainability in production and consumption in fashion industry. The standards in Science consisting of composition of air, combustion and air pollution are closely related to the SDG about Climate Action (Table 4). However, in RBT there is no specific standards link to this SDG. As design challenge is the focus of all the combinations, similar standards regarding the design process from RBT and Mathematics were integrated in the four combinations. As for the other SDGs such as Life below water, Life on Land, Affordable and Clean Energy, Good Health and Well-being, Innovation and Infrastructure, the standards in Grade 7 particular in Science do not explicitly cover these few SDGs. It can only include the basic standards in regards to design process. There are no standards in the Grade 7 Science that comprehensively relate to the other SDGs such as Good Health and Well Being, Clean Water and Sanitation, Life on Land, Life in Water. They may relate to the curriculum standards of science or RBT of higher levels.

Each of the combination was reorganized to make it appropriate and relevant to the life of the students. The design challenge serves as the open-ended problem for each combination. A design challenge was formulated according to the relevant learning to the SDG theme, the local context of the students and appropriate to the selected combination of standards. Related new concepts or skills were included as enrichment activities. The suggested implementation period is based on the completion on the selected prior key knowledge and skills as listed in the planned curriculum map of the three subjects. For example, in Zero Hunger, the fertigation system of RBT and data handling in mathematics were scheduled to be completed in August. Therefore, all the design challenge activities most probably can only be done after the month of August.

The planning of after-school STEM education programs can be established through the integration of existing curriculum standards of the individual STEM subjects focusing on the theme from SDGs. This study involved the application of Grade 7 Science, Mathematics and Design of Technology (RBT) curricular standards, at the same time incorporating new concepts and skills that may relate to the design challenge. Learning experience of students can be enhanced through STEM subjects' standards integration as it facilitates deeper understanding and building connections among centrals concepts (Yoder, Bodary, & Johnson, 2016). The use of level appropriate curricular standards served as prior knowledge that may help the students gain the motivation and confidence to carry out the design challenge. Prior knowledge facilitates the construction of new experience (Roschelle, 1995). Prior knowledge also influences the students' perception and attention and it affects learning subsequent new concepts (Cook, 2006). This is one of aspect of constructivism perspectives in learning in which assimilation and accommodation of new knowledge can happens through the changes and restructuring of prior knowledge (Piaget, 1952). Without prior knowledge, students may find difficult to comprehend or complete the lesson or activities. Some may be able to complete the task for the sake of completing them but without able to acquire new understanding or skills. Hence, it can result in students learning something opposed to the intended goals or objectives (Roschelle, 1995).

At the same time, the design challenge involved a number of new concepts and skills that are necessary to complete the task. For example, all design challenges involved the EDP. This may seem to be new to the students as there is no explicit mention of EDP in any of the curricular standards. However, there are similarities in the RBT curricular standards of design process with the EDP. Students' previous knowledge and skills on design processes acquired during the RBT lesson may serve as an important bridge whereby they can build on this new approach. Sustainable agriculture is another new concept which may require basic understanding and skills on sustainable farming which are not taught explicitly in the classroom lesson. Basic knowledge on photosynthesis and plant reproduction in the form one science curriculum and the fertigation technology in the RBT may serve as a prior knowledge for students to assimilate and accommodate the new concepts and skills of sustainable agriculture. The incorporation of new concepts and skills serve as potential development level as described in the social constructivism perspective in learning (Vygotsky, 1978, 1997). Vygotsky (1978) described that in order for cognitive change to occur in the level, learners must engage and interact to jointly construct the new knowledge. There must also be facilitation, support or collaboration with more capable peers or teachers known as scaffolding, referring to the assistance given to perform a task beyond ones capabilities (Wood, Bruner, & Ross, 1976). Hence, teamwork, communication, collaboration and teacher's facilitation have to be intentionally included in designing or selecting the instructional strategies of this after-school curriculum.

The inclusion of EDP as one of the main approaches is one way to incorporate engineering in STEM education as practiced by many STEM researchers (English, King, & Smeed, 2017; English & King, 2015; Guzey, Moore, & Harwell, 2016, Barroso et al., 2016). Through engineering, students finds relevance in the application of science and mathematics concepts (Clough & Olson, 2016). EDP involving iterative cycle of defining problem, planning, implementing, testing, evaluating and communicating the solution is the focus of engineering. These steps involved the application of scientific and mathematical concepts and skills such as scientific inquiry process and mathematical reasoning. Therefore, EDP can be seen as cohesive force that blends all the relevant STEM discipline. In order to incorporate EDP, level appropriate design challenge is formulated focusing on solving a contextual problem. The design challenge has to be authentic, open-ended, motivating, engaging, level appropriate and allowing students to connect to their prior knowledge (Cunningham & Lachapelle, 2016; Guzey, Moore, Harwell, & Moreno, 2016; Slough & Milam, 2013). The task has to authentically relate to the contextual problems relevant to the students. However, Clough and Olson (2016) cautioned that it is almost impossible to focus on things or situations that are relevant to every student as each of them has different interest and abilities. One situation may be a concern to a student but may not be relevant to another. Furthermore, their interest and abilities are ever shifting at this young age. Hence, it is important to connect students with knowledge, concepts, skills or experiences that are beyond their immediate relevance as this will expand their thinking and learning. The focus of SDGs as the contextual issues is one way to broaden the students' learning. Some of the SDGs may not have immediate relevance to the students' lives but teachers can play an important role to create awareness or connection to the students. It opens the students' horizon and perspectives, engaging them into relevant global issues, empowering them to make decision and take responsible actions.

For future research, each of the planned standard-based integrated STEM design challenge need to be written in measurable learning objectives. Clear and precise learning objectives are crucial in linking instruction and assessment. Multi-dimensional assessment plan that align with the standards can be developed to validly measure students' learning of STEM content and skills. This may include development of rubrics that focus on evaluating the learning process throughout the design challenge. Educators may consider various templates or models to develop the material. Some of the available templates are the BSTEM resource module and STEM Road Map. All these have to be tested iteratively through pilot implementations using appropriate instructional strategies. This helps to ascertain the relevancy of the various standards to the respective design challenge and whether there is a need for other essential concepts and skills to be included. It also helps to identify any problems that need to be addressed and rectified. The pilot implementation will facilitate the verification process through expert reviews that will provide the validity and reliability of these programs.

5.0 CONCLUSION

By using the relevant contextual issues such as the SDGs to integrate the existing level appropriate curriculum standards of STEM subjects can be an initial start for the planning of after school STEM education programs. The description offers a way to facilitate the planning of standard-based STEM education programs. It emphasizes the aspect of integration and contextual problem solving in STEM education as an integrated learning approach. The related multidisciplinary concepts and skills are organized and connected through the application of EDP in order to solve a real-world problem. The contextual problems are relevant to the global issues described in the Sustainable Development Goals (SDG) by UNESCO (2017). This makes learning relevant and meaningful as it empowers learners to make informed decision and take responsible action in their own context. For future studies, detailed learning objectives, lesson plan that incorporate the relevant instructional strategies and comprehensive assessment plan need to be developed before the pilot implementation phase. The pilot implementation will help to verify the content and to identify problems that need to be rectified. It is aspired that the replication of this procedure can be used to plan after-school STEM programs that are level appropriate and relevant to the context of the students.

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